



Technology and Engineering Literacy Profile of High School Students: Comparison between STEM and Non-STEM Learning

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Abstract: Technology Engineering Literacy (TEL) represents an essential competency in the 21st century, encompassing the ability to understand, evaluate, and apply technological and engineering concepts in everyday life and professional settings. This study was conducted to compare the TEL profiles of high school students engaged in Science, Technology, Engineering, and Mathematics (STEM) and non-STEM fields, with a particular emphasis on the renewable energy topic. The research employed a quantitative approach and involved 125 high school students, who were selected by purposive sampling techniques. Data were collected utilizing a TEL test instrument specifically designed for this research. Mann-Whitney analysis using SPSS 26 revealed a significant difference between STEM and non-STEM groups. Additionally, the TEL profiles of STEM and non-STEM students were evaluated by examining the percentages of complete and incomplete achievements. The findings show that students participating in STEM learning demonstrated a superior TEL profile compared to their non-STEM peers. Specifically, regarding the understanding of technological principles, 89% of STEM students completed the assessment, whereas only 75% of non-STEM students achieved this. In the context of developing solutions and reaching goals, 84% of STEM students met the completion criteria, in contrast to 63% of non-STEM students. For the technology and society dimension, 87% of STEM students completed the assessment, compared to only 59% of non-STEM students. In the design and systems area, 89% of STEM students completed the tasks, while 81% of non-STEM students did. Lastly, in the Information and Communication Technology (ICT) domain, 82% of STEM students reached the completion category, while merely 60% of non-STEM students did. These results emphasize the significant impact of STEM learning in enhancing students' technology engineering literacy, thereby equipping students with essential skills relevant to the needs of the 21st century.

Keywords: technology_and_engineering_literacy, STEM, renewable_energy.

▪ INTRODUCTION

Rapid technological advancements in the era of globalization have significantly transformed various aspects of human life. These developments not only affect how individuals communicate, work, and learn, but also necessitate that society cultivates the ability to adapt to these changes. STEM education promotes lifelong learning across diverse domains, with active learning strategies, particularly online formative assessment tools, being increasingly recognized for their instructional value. These tools play a critical role in enhancing Technology and Engineering Literacy (TEL) by providing students with interactive and feedback-rich environments that support the development of technological understanding and problem-solving skills (Jeong, González-Gómez, & Prieto, 2020). As the complexity of global society continues to expand, a robust understanding of technology and engineering becomes essential, as these concepts are

integral to numerous aspects of contemporary life (ITEEA, 2020; Moye & Reed, 2020). Technological and engineering literacy can be defined as the capacity to utilize, comprehend, and apply technology, as well as to understand the principles and strategies necessary for developing solutions and achieving specific goals. Technology is understood to be any modification of the natural environment to meet human needs or desires. At the same time, engineering is characterized by a systematic and iterative approach to the design of products, processes, and systems.

TEL is essential for preparing students to effectively understand, utilize, and design technology that addresses complex real-world challenges. TEL provides a strong foundation that empowers students to become not only competent but also creative and innovative in solving problems. With TEL, students gain invaluable knowledge about technology and the ability to apply engineering principles in real-life situations, resulting in effective and sustainable solutions. Recent studies clearly showed that the TEL skills of Indonesian students are currently at a low level, emphasizing the urgent need for targeted efforts to enhance these skills through the development of educational resources that meet the demands of the 21st century. Moreover, findings from research employing the TEL instrument adapted from the National Assessment of Educational Progress (NAEP) highlight that 69.2% of junior high school students are classified as proficient, while 15.4% are in the partial category. Another 15.4% have yet to achieve proficiency in understanding technological principles (Hamka, Suwarma, & Anwar, 2024). This data reinforces the necessity for strategic interventions to improve TEL competencies among students.

The integration of Science, Technology, Engineering, and Mathematics (STEM)-based learning constitutes a highly effective methodology for improving students' TEL. These findings were reinforced by Margot & Kettler (2019) who found that the integration of engineering design within science instruction not only improved students' engagement but also enhanced their abilities in constructing and evaluating systems are key competencies in TEL (Kelley, 2016). STEM education plays a crucial role in developing essential competencies such as critical thinking, collaboration, and creativity while providing authentic engagement with real-world problem-solving scenarios. This integrative approach facilitates the cohesive merging of various content areas (Cardullo & Burton, 2025; Tran, 2018). Teachers are encouraged to integrate technology and engineering elements into their learning, thereby equipping students to address global challenges and adapt to the rapidly evolving technological landscape. In Indonesia, a marked decline in interest in science has emerged as a critical issue that necessitates intervention. The government has initiated various strategies, including the implementation of the Merdeka curriculum, which provides educators with enhanced opportunities to collaborate with diverse groups in fostering meaningful and engaging learning experiences. The application of STEM as an interdisciplinary framework has consistently demonstrated substantial improvements in student learning outcomes at both secondary and higher education levels (López-Meneses, Cáceres-Tello, Galán-Hernández, & López-Catalán, 2025; Phillips & Zwicky, 2018). STEM integration involves combining science, technology, engineering, and mathematics to address real-world problems, leveraging students' experiences to develop essential 21st-century skills.

Numerous studies have decisively illustrated the progress of STEM education in Indonesia. Their research findings indicated that STEM-based modules and physics e-

books, which incorporate self-regulated learning methodologies, serve as effective alternative resources for addressing the topic of global warming within the physics curriculum. Additionally, the integration of technology, particularly through artificial intelligence applications such as chatbots, plays a significant role in advancing students' Technological Enhanced Learning (TEL). Moreover, data visualization is essential for effectively conveying patterns within quantitative data, thereby establishing data visualization literacy as a primary objective of STEM education (Brockbank et al., 2025; Valeri, Nilsson, & Cederqvist, 2025). The government strongly recommends the prioritization of project-based learning within Indonesia's education system. The effective implementation of this approach is poised to significantly enhance students' TEL achievement profiles. This recommendation is aligned with the principles of STEAM education, which necessitates that educators adopt a project-based curriculum to fully leverage the benefits of STEAM learning. Such methodologies are integral to the development of students' critical and creative thinking, as they require the integration of knowledge across multiple disciplines (Mao & Hong, 2025; Thoma, Farassopoulos, & Lousta, 2023). Experts claim that future challenges, like the energy crisis and global warming, cannot be effectively tackled by just one discipline. Instead, these issues demand collaborative involvement from various stakeholders (Arango-Caro et al., 2025; Lee & Park, 2025).

The topic of renewable energy holds significant relevance in the context of STEM education, as it encompasses various interconnected disciplines. Engaging with renewable energy enables students to understand the scientific concepts behind alternative energy sources, apply technology to develop innovative solutions, and design and evaluate efficient energy system prototypes. This aligns with STEM education, which focuses on developing problem-solving skills (Wahono, Lin, & Chang, 2020). Moreover, this subject area fosters the assessment of TEL, which measures students' ability to integrate knowledge and skills from multiple STEM fields to tackle real-world issues in energy technology. Future generations will face complex challenges within living systems, including sustainability issues like climate change and the limited availability of renewable energy resulting from the depletion of fossil fuel reserves (Abdurrahman et al., 2023). By emphasizing this topic, students not only enhance their technical proficiency but also acquire a deeper understanding of the global challenges and sustainable solutions associated with the transition to renewable energy (Hidge & Aktamis, 2022).

In the contemporary educational environment, many teachers face significant challenges and constraints in their efforts to design and implement effective STEM learning initiatives. A primary challenge is the inadequate availability of supporting facilities, particularly in schools located in regional areas. To effectively address this issue, it is important to enhance the teachers' professional capability in integrating STEM education. This can be achieved through the development of teacher training programs (Suwarma, Riandi, Komano, Permanasari, Sudarmin, Widyatmoko, 2023). Accordingly, the research question addressed in this study is whether a significant difference exists in the Technology and Engineering Literacy profiles of high school students who engage in STEM learning as opposed to those who participate in non-STEM learning focused on renewable energy content.

▪ METHOD

Participants

The population for this study consists of all students in West Java. The sample included 125 tenth-grade students, with 77 students engaging in learning through the STEM (Science, Technology, Engineering, and Mathematics) approach and 48 students participating in learning through a non-STEM approach. A purposive sampling method was utilized to select participants from two cities, Tasikmalaya and Bandung, to mitigate potential bias associated with urban or rural educational settings. The students were selected based on the criterion that their renewable energy lessons integrated STEM practices (including both scientific and engineering practices), while the non-STEM group engaged in renewable energy lessons without the integration of STEM (non-STEM) shown in Table 1. This thoughtful distribution enhances the rigor and relevance of the study's findings, accurately representing the diverse educational experiences of students in West Java. On initial comparison, the two groups (STEM and non-STEM) may not be inherently equivalent, as they were selected purposively based on their participation in distinct educational approaches. However, to ensure the comparability of the groups at the outset, efforts were made to control for potential confounding variables such as students' initial academic abilities, socio-economic background, and teacher quality. One of the key strategies employed was the selection of students with high academic achievement from each participating school. This approach aimed to minimize variability in baseline academic competence, thereby enhancing the internal validity of the comparisons made between the STEM and non-STEM groups.

Table 1. Comparison activities for both STEM and non-STEM

Method	Learning Activities
STEM	The learning activities on renewable energy topics were conducted using Problem-Based Learning (PBL) and Project-Based Learning (PjBL) models, integrating the STEM approach, particularly scientific and engineering practices. Students were divided into groups and assigned to develop prototypes as solutions to the given problems.
Non-STEM	The learning activities on renewable energy topics were carried out using the Direct Instruction and Problem-Based Learning (PBL) models, involving group presentation assignments that focused on analyzing renewable energy issues, without the development of prototypes.

Research Design and Procedures

This research employs a quantitative approach to evaluate students' technology and engineering literacy (TEL). The study utilizes a descriptive quantitative design. The sample consists of two groups with different learning characteristics (STEM and non-STEM), each administered a TEL assessment delivered through the Nearpod platform at nearpod.com. The research was conducted over three weeks (1 meeting for each week), aligned with the physics lesson schedules at each participating school. The research procedure entailed administering a 30-minute TEL test containing 10 questions to both STEM and non-STEM students. Following the test, the scores were compiled and analyzed to assess any significant differences in the TEL profiles between the two groups.

Instruments

The instrument employed in this study was developed by utilizing the Technology and Engineering Literacy (TEL) framework established by the National Assessment of Educational Progress (NAEP) (National Assessment Governing Board, 2018). This instrument consists of ten multiple-choice questions. The aspects measured were developing solutions, achieving goals, and understanding technological principles in the areas of technology and society, design and systems, and Information and Communication Technology (ICT). The TEL aspects measured were select among alternatives, describe features of a system or process, identify examples of a system or process, produce an alternative design or product, design and build a product using appropriate processes and materials, describe features and functions of ICT tools, predict consequences of a technology, transform from one representational form to another, conduct experiments using digital tools and simulations, and select and use appropriate tools to achieve a goal. The TEL targets evaluated encompass the understanding of technological principles and the development of solutions aimed at achieving specific objectives, with a focus on three principal areas: Technology and Society, Design and Systems, and Information and Communication Technology (ICT). This instrument has been extensively tested and validated by experts. The validation involved five experts, consisting of content experts, evaluation experts, and practicing teachers. The results of the validation were analyzed using Aiken's V statistic, which yielded an average coefficient of 0.88. According to the criteria established by Aiken (1985), an item is considered valid if the coefficient value exceeds 0.8. Therefore, these results indicate a high level of validity. The data collection for the TEL profile was conducted offline. Participants completed a 10-item TEL test via a Nearpod link within 30 minutes. The Nearpod platform presented both the stimulus materials and the problems to be addressed. After the 30-minute session concluded, the Nearpod session automatically closed, and participants' responses were saved automatically. This is an example of a TEL question that has been developed.

Table 2. Example of TEL question

Question type	Assessment Areas	Content Classifications
Multiple Choice	Information and Communication Technology (ICT)	Developing Solutions and Achieving Goals
Indicator Identify examples of a system or process.		
You can do the virtual simulation on the website: https://phet.colorado.edu/sims/html/energy-forms-and-changes/latest/energy-forms-and-changes_in.html .		
You have conducted a simulation on energy transformation. Based on the simulation, which of the following statements best describes the energy transformation process in the system?		
a. The kinetic energy from pedaling the bicycle is directly converted into heat energy in the container of water.		
b. The mechanical energy from pedaling the bicycle is converted into electrical energy by a generator, which is then transformed into heat energy that warms the water in the container.		
c. The electrical energy from the generator is used to drive the bicycle wheels, allowing the child to pedal faster.		
d. The potential energy in the water increases due to the electric current from the generator.		
Answer key:		

-
- b. The mechanical energy from pedaling the bicycle is converted into electrical energy by a generator, which is then transformed into heat energy that warms the water in the container.
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This question targets the TEL indicator “Identify examples of a system or process” by requiring students to recognize and describe energy transformations within a system presented in a virtual simulation. Students are prompted to engage in a simulated activity that demonstrates the transition of energy from mechanical (pedaling a bicycle) to electrical, and finally to thermal energy used to heat water. The item is designed to assess students’ comprehension of how energy can be systematically converted from one form to another, as seen in a basic energy generation system involving a bicycle and a generator. To measure this understanding, students must choose the statement that best reflects the energy transformation sequence.

Data Analysis

The research data were analyzed using statistical methods. First, a normality test was conducted using IBM SPSS Statistics 26. The results of the Kolmogorov-Smirnov test showed a p-value of 0.000 for the STEM group and 0.027 for the non-STEM group. Since both groups obtained p-values less than 0.05, it was concluded that the data were not normally distributed. Consequently, to examine statistical differences between the STEM and non-STEM groups, the Mann-Whitney U test was employed. The analysis using SPSS revealed a p-value of 0.000 ($p < 0.05$), indicating a statistically significant difference between the two groups. Additionally, to determine the percentage of TEL profile achievement for each indicator, a descriptive analysis was conducted based on the TEL assessment criteria established by NAEP. The acquired information was quantitatively processed using Microsoft Excel software. For multiple-choice items, responses were categorized into two types: complete if the student's answer was correct, and incomplete if the answer was incorrect or left unanswered.

▪ RESULT AND DISCUSSION

This study aims to evaluate the achievement of the students’ TEL profiles among students engaged in learning through a STEM approach compared to those participating in non-STEM learning models, such as direct instruction. Participants were administered a TEL test instrument utilizing Nearpod media, with the content aligned to the Merdeka curriculum phase E, explicitly focusing on renewable energy. The TEL assessment is meticulously designed to assess students’ knowledge in technology and engineering. This research examines three core aspects of technology and engineering literacy. The first aspect pertains to the understanding of technological principles, emphasizing students’ knowledge and comprehension of technology, as well as their capacity to think critically and reason based on that knowledge. The second aspect involves the development of solutions and goal achievement, focusing on students’ ability to apply their technological knowledge, skills, and tools to address problems and reach objectives. The TEL assessment utilized in this study comprises ten multiple-choice questions. In accordance with the NAEP assessment guidelines, responses were categorized as either complete or incomplete. A response was classified as complete when the student answered correctly, while it was classified as incomplete if the student either answered incorrectly or did not answer.

The findings of this study are confined to the objective of comprehending technological principles, formulating solutions, and achieving specified goals across three main areas: technology and society, design and system, and ICT. In accordance with these objectives and domains, the analysis encompassed ten distinct indicators, which include: selecting among alternatives, describing the features of a system or process, identifying examples of a system or process, producing an alternative design or product, designing and constructing a product utilizing appropriate processes and materials, describing the features and functions of ICT tools, predicting the consequences of a technology, transforming information from one representational form to another, conducting experiments with digital tools and simulations, and selecting and employing suitable tools to accomplish a goal. The analysis of the achievements related to the TEL profile was evaluated against the assessment targets as show in Figure 1.

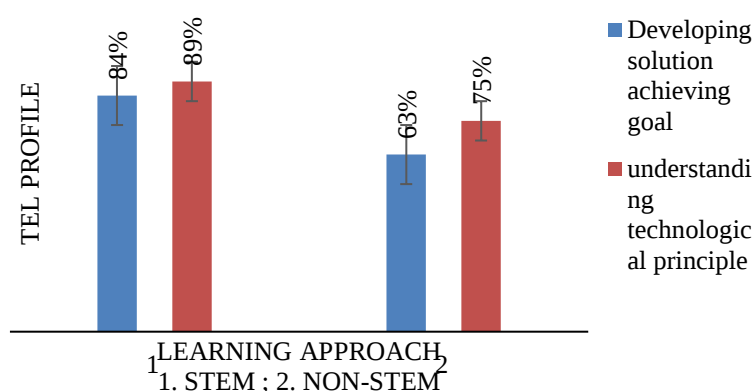


Figure 1. TEL profile based on assessment target

The graph in Figure 1 shows a comparison of students' TEL profile achievements in the two main dimensions of the target assessment, namely developing solutions and achieving goals, and understanding technological principles. In general, students involved in STEM-based learning have shown higher achievements than non-STEM students in both TEL dimensions measured. Furthermore, the Mann-Whitney U test was conducted to examine whether there was a statistically significant difference in Technology and Engineering Literacy (TEL) scores between students who received STEM-based instruction and those who participated in non-STEM learning. The results revealed a Mann-Whitney U value with an asymptotic significance (2-tailed) value of 0.000. Since the p-value is less than the significance threshold of 0.05, it can be concluded that there is a significant difference in TEL scores between the two groups. These findings support the effectiveness of STEM instruction in enhancing students' ability to understand and apply technological concepts through scientific and engineering practices. Based on descriptive analysis, in the developing solutions and achieving goals indicator, STEM students have achieved 84%, while non-STEM students have only achieved 63%. This 21% difference indicates that the STEM approach is more effective in training students to design solutions and achieve goals systematically, skills that act as the core of engineering processes and technology-based problem-solving. This aligns with Kelley (2016), who has stated that the STEM learning approach facilitates the integration of science, technology, and engineering through design-based activities and solving real

problems. In the understanding technological principles dimension, STEM students have also increased, with an 89% completion compared to the non-STEM group, which has only achieved 75% completion. Although the difference is less than in the first indicator, it still shows that the STEM approach has provided a deeper conceptual understanding of technological principles. This is supported by the findings of Daugherty, Carter, & Sumner (2021), who have stated that the integration of technology in STEM learning enables students to study, evaluate, and apply technological principles in various life contexts.

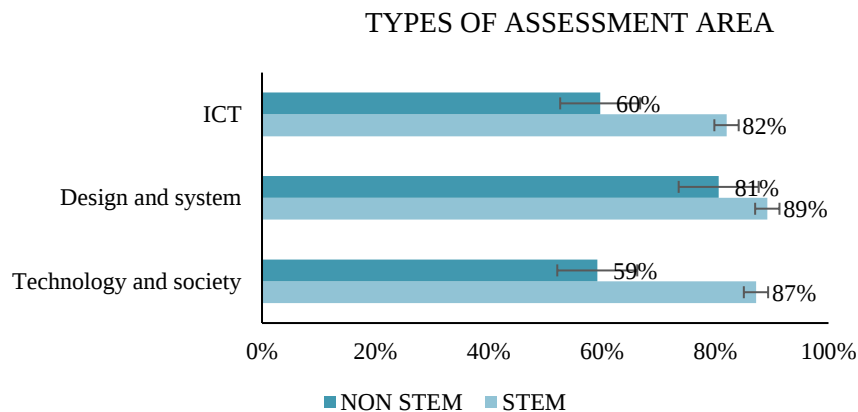


Figure 2. TEL profile based on assessment area

Figure 2 illustrates a comparative analysis of Technology and Engineering Literacy (TEL) achievements among students categorized by their learning backgrounds in STEM and non-STEM fields. The findings reveal that students from the STEM group consistently surpass their non-STEM counterparts in three main assessment areas: ICT, Design and Systems, and Technology and Society. In the ICT domain, STEM students demonstrated an achievement level of approximately 82%, significantly higher than the 60% achievement reported by non-STEM students. This disparity indicates the effectiveness of the STEM educational approach, which integrates digital technology and simulation tools, thereby enhancing students' understanding of the functions and applications of ICT tools (Cencelj, Aberšek, Aberšek, & Flogie, 2019). For example, students in the STEM group showed notably higher achievement in the indicator *"Describe features and functions of ICT tools,"* which can be attributed to repeated exposure to interactive software and data-driven technologies during learning activities. Additionally, the STEM group outperformed the non-STEM group in the indicator *"Conduct experiments using digital tools and simulations,"* reflecting the effectiveness of STEM environments that simulate real-world systems for testing hypotheses and analyzing outcomes. Such integration of scientific and engineering practices allows students to engage in inquiry-based learning, where they design solutions, interpret data, and evaluate trade-offs using digital resources. These experiences not only align with the cognitive processes outlined in the TEL framework but also mirror the demands of 21st-century technological literacy. By contrast, the non-STEM group, which lacked structured exposure to engineering processes or technology-enabled experimentation, demonstrated lower performance in these domains. Therefore, the observed disparity in

TEL scores can be traced to the specific instructional design of STEM learning, which actively develops the competencies required to understand, apply, and evaluate digital tools and systems in a technologically mediated world. Such activities provide authentic contexts that strengthen students' conceptual understanding and practical application of technology, explaining why STEM students outperform their non-STEM peers in these areas. Similarly, in the Design and Systems area, which encompasses the skills required for solution design, comprehension of technological operations, and structured thinking, STEM students achieved nearly 90% in the complete category, compared to a 75% achievement rate among non-STEM students. This trend highlights the critical role of project-based learning and engineering design processes in the STEM curriculum, as asserted by (Kelley, 2016), who emphasizes that design and systems competencies are best cultivated through hands-on experiences and reflective problem-solving practices. Furthermore, in the Technology and Society area, a notable achievement gap was observed with STEM students attaining close to 90%, while non-STEM students achieved only around 62%. This difference indicates that students with STEM exposure are more adept at analyzing the social, environmental, and ethical ramifications of technology usage, which are essential components of TEL. Understanding the interplay between technology and society is a fundamental aspect of STEM education, equipping students to become technologically aware and socially responsible citizens. In conclusion, these findings robustly support that the integration of a STEM educational approach significantly enhances all aspects of TEL.

This study conducts a comprehensive review of both target assessment and area assessment, while also analyzing the TEL profiles of STEM and non-STEM students. The analysis focuses on TEL indicators established by the NAEP as outlined in the NAEP Framework 2018. A total of ten indicators are evaluated, with the results detailed in Figure 3.

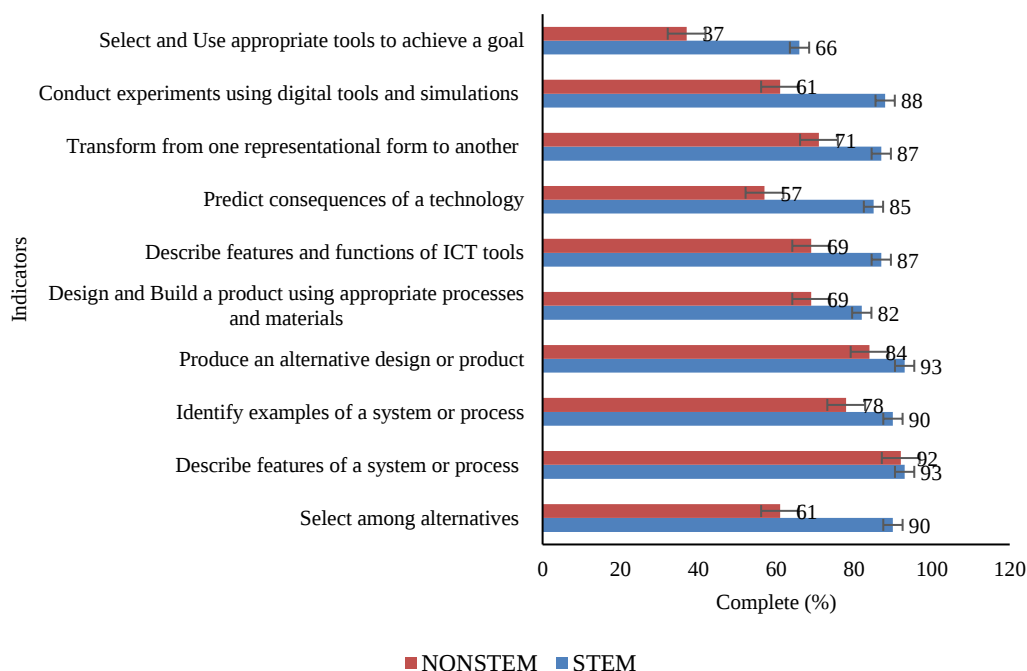


Figure 3. Students' TEL profil based on indicators

Based on the data presented in Figure 3, the data show that students in the STEM group consistently achieved higher completion rates across nearly all TEL indicators. Specifically, STEM students outperformed their non-STEM peers in key areas, such as "Conduct experiments using digital tools and simulations" (88% vs. 61%) and "Describe features and functions of ICT tools" (87% vs. 69%). These advantages can be attributed to the integration of engineering design tasks and digital simulations in STEM classrooms, which promote hands-on engagement and contextual application of concepts. However, a closer examination reveals that the performance gap is relatively narrow or even negligible on specific indicators. For example, in the indicator "Describe features of a system or process," the non-STEM group achieved a comparable completion rate of 92%, just slightly below the STEM group's 93%. This finding suggests that when learning activities involve observation, explanation, or discussion-based tasks such as presentations or text analysis, non-STEM approaches can also effectively support conceptual understanding. Such activities often rely on verbal reasoning and theoretical analysis, which may align well with the existing learning habits of students in non-STEM classrooms, where emphasis is placed on conceptual knowledge rather than practical execution. Moreover, the relatively high completion rate in "Produce an alternative design or product" (84% for non-STEM students) indicates that creative thinking and design ideation are not confined to STEM settings. With appropriate support, non-STEM environments can also foster innovation, particularly when collaborative group work is involved. In summary, while STEM pedagogy excels in developing applied TEL competencies, particularly those involving experimentation and tool-based manipulation, it is essential to recognize that non-STEM learning environments can still yield strong outcomes in conceptual explanation, critical reflection, and creativity when properly structured. Rather than viewing STEM as a complete replacement, these findings suggest the potential value of integrating the strengths of both approaches to create a more holistic and inclusive model for developing technological and engineering literacy.

On the other hand, this finding suggests that the ability to effectively select and utilize tools remains a significant challenge for non-STEM students, likely due to their limited exposure to hands-on experiences in project-based or experimental learning environments. In conclusion, these data emphasize the critical need to enhance STEM-based learning initiatives to develop students' TEL profiles. The skills cultivated through STEM methodologies, including design thinking, technology exploration, and digital experimentation, have been demonstrated to support superior performance in assessments related to technology and engineering literacy.

This distinction in achievement substantiates the conclusion that STEM education not only enhances students' practical competencies but also fortifies their theoretical comprehension of technological concepts. Such findings indicate that STEM-based instruction plays a pivotal role in advancing students' technological and engineering proficiencies. Conversely, non-STEM learning typically yields a more restricted understanding, particularly in terms of applying technology for creative and effective problem-solving. STEM-based learning provides students with the essential opportunity to apply their knowledge effectively and address real-world challenges through engineering processes. This instructional method not only deepens students' understanding of fundamental concepts but also promotes creativity by motivating them to generate innovative solutions (Peters-Burton, 2019; Vieira, Crompton, Marrone, &

Singh, 2025). As a result, it is imperative to strengthen a cross-disciplinary and project-based learning approach to elevate the overall quality of students' technological and engineering literacy. Consistent with the findings of prior studies, the implementation of Project-Based Learning with an emphasis on STEM principles (PjBL-STEM) at the higher education level indicates its potential to enhance technological and engineering literacy (TEL) (Nova, Suwarma, Winarno, & Simanjuntak, 2024). Moreover, a considerable majority of students, totaling approximately 80%, express favorable attitudes towards STEM careers (Matete & Kombe, 2025). Additionally, students engaged in the STEM domain have articulated that the process of research writing has provided them with critical insights and improved clarity regarding their research topics (Fanguy, 2024).

Non-STEM students require targeted interventions, including practical activities, technology-based projects, and in-depth discussions regarding the role of technology in society. These interventions should incorporate practical activities, technology-based projects, and thorough discussions regarding the role of technology in society. Educators may implement hands-on projects that involve the construction of simple devices or the execution of experiments utilizing technology, thereby promoting both creativity and the development of problem-solving skills. Additionally, facilitating discussions about the impact of technology, including debates or case studies examining its influence across various sectors, will enable students to analyze its societal implications critically. Collaborative group work is also a valuable approach, allowing students to work together to devise solutions for real-world problems, employing technology as a fundamental tool. Such interventions not only enhance students' comprehension of technology but also equip them with the necessary skills to navigate and contribute meaningfully in an increasingly technology-driven world. These steps are important to ensure they do not lag in mastering TEL. Furthermore, it is essential for educational institutions to contemplate broadening the integration of STEM principles within non-STEM curricula to foster a more equitable and inclusive technological literacy for all students (Hamka et al., 2024; Li et al., 2019). It is essential for future generations to cultivate STEM literacy, which is understood as a dynamic process and a critical capability enabling individuals to apply knowledge, pose inquiries, collaborate effectively, appreciate diverse perspectives, and enhance their overall quality of life (Peng, Zhao, & Zheng, 2025; Retno, Purnomo, Hidayat, & Mashfufah, 2025). The integration of STEM principles into non-STEM curricula is a critical measure to bridge the TEL gap among diverse student groups.

The limitations of this study are associated with several factors that may affect the validity and generalizability of the findings. First, the research was conducted using a sample of schools from a specific region, which limits the extent to which the results can be generalized to a wider population. Second, the instrument employed to measure Technological and Engineering Literacy (TEL) may not adequately encompass all dimensions of skills required across various educational contexts (communication and collaboration). Additionally, external variables, such as socioeconomic background, access to technology, and teaching quality, may have influenced the findings; however, these factors were not fully considered in this study. Lastly, Despite using a quantitative approach, the instrument may not fully capture the subtleties or deeper differences in students' understanding and application of TEL.

▪ CONCLUSION

This study found that students who participated in STEM-based learning demonstrated significantly higher levels of Technological and Engineering Literacy (TEL) compared to those in non-STEM learning environments. Statistical analysis using the Mann-Whitney U test confirmed this difference to be significant ($p = 0.000$), indicating that the learning approach substantially impacts TEL development. Across key assessment dimensions, including understanding technological principles, solution development, technology and society, systems design, and information and communication technology, STEM students consistently outperformed their non-STEM peers. These findings underscore the value of integrating STEM principles into educational practices, particularly in enhancing students' capacity to understand, apply, and evaluate technological and engineering concepts. As the demands of the 21st century increasingly emphasize technological fluency, this research highlights the critical role of STEM education in preparing learners to meet future challenges, making it a compelling model for curriculum innovation and educational policy advancement.

The implications of this study highlight the critical role of STEM-based learning in equipping students with essential technology and engineering skills, which are crucial for their success in a rapidly evolving digital world. By fostering higher levels of TEL, STEM education can help bridge the gap between students' current abilities and future career demands. However, this study has several limitations, such as its reliance on a specific sample group (STEM) and a specific assessment medium that did not fully capture all dimensions of TEL (communication and collaboration). Future research could explore broader academic environments and incorporate more diverse assessment methodologies to more comprehensively assess the impact of STEM learning on TEL development. To maximize the potential of STEM education in improving students' technology and engineering literacy, policymakers and educators must prioritize the integration of STEM-based methodologies into the educational curriculum. This strategic focus will equip future generations with the essential skills needed to succeed in an increasingly technology-driven environment.

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